GRAND RIVER BASIN WATER MANAGEMENT STUDY

Investigation of Weir Aeration & Sediment Oxygen Demand at Small Dams in the Grand River Basin

File Report #RS-1

Ministry of the Environment
Ontario

INVESTIGATION OF WEIR AERATION & SEDIMENT OXYGEN DEMAND AT SMALL DAMS

IN THE

GRAND RIVER BASIN

FILE REPORT #RS-1

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FOREWORD

This file report is one of a series of technical documents prepared for the Grand River Basin Water Management Study. The information described herein was collected to provide input into the project undertaken through the Grand River Study Team at the request of the Grand River Implementation Committee.

The material contained in these reports is primarily technical support information, and, in itself, does not necessarily constitute policy or management practices. Interpretation and evaluation of the data and findings in most cases cannot be based solely on this one report but should be analysed in light of the full report "Grand River Simulation Model - Calibration, Verification and Application" to which it is related.

Because of their limited scope, these reports are only of interest to those directly involved in the project details, and consequently, only a limited number of copies are made available.

ACKNOWLEDGEMENTS

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INTRODUCTION

The water quality of a stream can be seriously affected by the presence of dams and weirs. These structures create pools which have dissolved oxygen (DO) levels above or below those normally expected in a free flowing stream of similar water quality. If there are sufficient nutrients in the water, excessive algal growth will be promoted and supersaturated DO levels will result. When there is no photo- synthesis taking place (for instance, at night), DO concentrations can fall below the desired levels since the waste assimilative capacities of the pools are often lower than those of free flowing reaches of the same stream.

Dams are also known to promote the accumulation of sediment. Chemical and biological processes in sediments - especially organic sediments - consume oxygen, and this phenomenon can cause significant reductions in DO in overlying waters. This is particularly the case in the thermally-isolated hypolimnetic waters of reservoirs.

One of the goals of the Grand River Basin Water Management Study has been to evaluate existing water quality in the Basin and remedial measures in the present and future that are required to attain provincial water quality objectives. To meet this goal, a dynamic water quality model was constructed to account for various sources and sinks of water quality in the megalopolis area (downstream of Waterloo-Brantford). In order to apply this model to sections of the river containing small dams, it was necessary to identify the gas exchange effect at weirs and the sediment oxygen demand behind these dams. Consequently, the objectives of this investigation were:

(a) to measure the effects of aeration at small dams on the instream dissolved oxygen concentrations for use in the dynamic water quality model calibration;

(b) to establish a general relationship between dam height and the weir aeration coefficient (W), if one exists.

(c) to measure the sediment oxygen demand (SOD) caused by the accumulation of sediment upstream of the dams examined in (a).

Part I of this report deals with the weir aeration at the dams and Part II with the sediment oxygen demand behind some of the dams.

STUDY AREA

The study area is in the Grand River basin. Dam locations are shown on a basin map in Figure 1. The sites are at the small dams at:

(a) The Speed River at Hespeler
(b) The Speed River at Preston
(c) The Grand River at Paris
(d) The Grand River at Galt

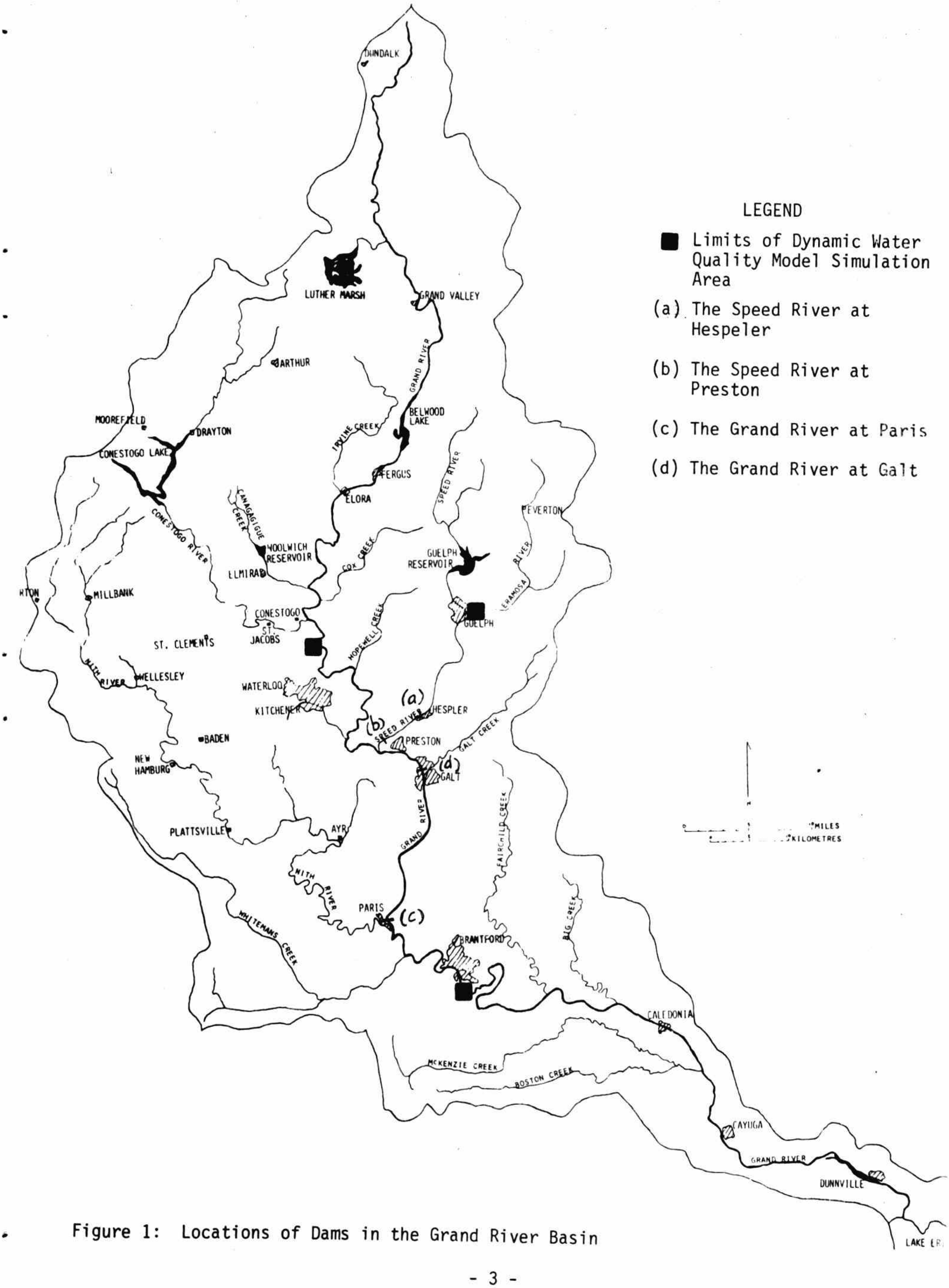

Figure 1: Locations of Dams in the Grand River Basin

PART I: WEIR AERATION

DATA COLLECTION: EIL meters with probes and connected Rustrak recorders were used to measure dissolved oxygen and temperature over a 24-hour period. DO profiles were taken across the crest of the dam and below the dam to check for representative locations to place the probes. One probe was placed at the crest of the dam, and another within 50 m of the dam on the downstream side (see Figure 2 for schematic diagram of weir aeration). Care was taken to avoid placing the downstream probe in turbulent or eddy locations.

A steel tape was used to measure the static head loss at each site. The details of individual dam structures and the results of the data analyses are provided in subsequent sections.

INSTRUMENT CALIBRATION: The EILs were calibrated in the laboratory before they were transported to the site. At the site, they were checked simultaneously at the same spot in the stream to ensure uniform calibration before setting them in place. They were checked once more in the laboratory at the end of each survey to determine whether any deviation occurred in calibration during the survey. Any difference was then linearly distributed between the initial and final readings.

AERATION THEORY: Water flowing over weirs or spillways of dams can be aerated or deaerated depending upon the ambient upstream DO concentrations in relation to the air saturation concentration (C_S). When there is excessive algal growth and photosynthesis is taking place, upstream DO levels can be elevated above saturation. This condition is called supersaturation and the oxygen deficit associated with it is considered to be negative. Conversely, the deficit associated with the undersaturation condition is positive. The aeration capacity of a weir is usually expressed by a coefficient defined as follows:

$$W = (d_A - d_B)/d_A$$

where W = weir aeration coefficient

$d_A = (C_S - C_A)$ = upstream DO deficit, mg/L

$d_B = (C_S - C_B)$ = downstream DO deficit, mg/L

C_A and C_B are the upstream and downstream DO concentrations, respectively;
and C_S is the DO saturation concentration, which is temperature-dependent.

N.B. If C_A is supersaturated,
d_A is negative since C_A is larger than C_s
Conversely, if C_A is undersaturated,
d_A is positive, since C_A is smaller than C_s

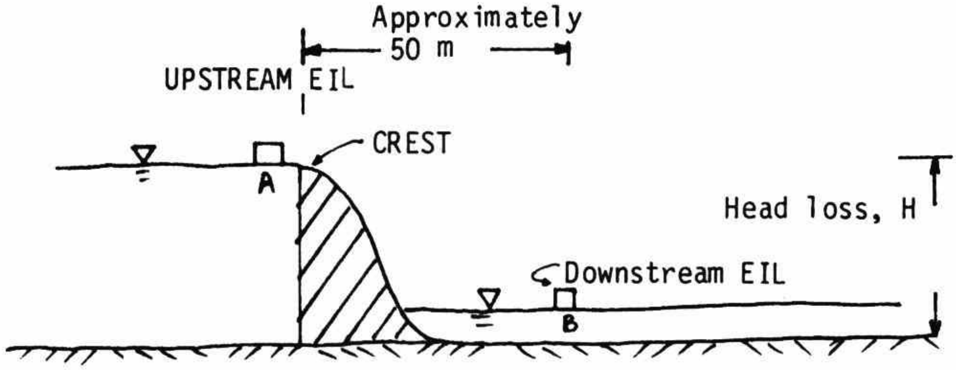

FIGURE 2 - SCHEMATIC DIAGRAM FOR WEIR AERATION

W is then used to calculate the effect of the dam on the DO concentration, i.e., $d_B = d_A(1-W)$

The coefficient W varies with the height of dam, temperature of air and water, dam hydraulics, depth of water at the foot of the dam, flow rate and water quality.[1]

DATA REDUCTION: Selection of valid DO concentration data to determine the weir aeration coefficient was based on the criteria stated in Butts and Evans (1978). According to these criteria, the following four conditions must be met, based on the aeration theory which states that DO concentrations should move towards saturation for the data to be valid.

(a) When C_A and $C_B < C_S$; $C_B \geq C_A$
(b) When $C_A < C_S$; $C_B \leq C_S$
(c) When C_A and $C_B > C_S$; $C_B \leq C_A$
(d) When $C_A > C_S$; $C_B \geq C_S$

Detailed explanation about selection of valid data points was taken directly from Butts and Evans (1978); a verbation quote from their work appears in the Appendix.

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1 Thomas A. Butts and Ralph L. Evans 1978. "Effects of Channel Dams on Dissolved Oxygen Concentrations in Northern Illinois Streams", Illinois State Water Circular 132/78.

SITE INVESTIGATIONS

HESPELER: The dam in the Town of Hespeler is a broad-crested concrete structure, 3.35 m high with a sloping face, located on the Speed River (see Figure A1). Data collected during May 28-29, 1979, are presented in Table A1 in the Appendix. Three of the twenty-six data points were rejected based on the criteria mentioned above. Temperature ranged from 11.5 - 12.7^{o}C above and 13.0 - 13.6^{o}C below the dam. DOs ranged from 7.29 - 12.62 mg/L above and 9.64 - 11.96 mg/L below the dam. The weir aeration coefficients, calculated from the hourly data, are summarized in the Appendix in Table A2.

PRESTON: The Preston dam is a broad-crested concrete structure,1.52 m high with a sloping face, located on the Speed River in the Town of Preston. Continuity across the dam is broken by two piers, one of which is visible at the right side of Figure A2. A summary of the data collected during July 3-4, 1979 is presented in Table A3. All the data points were used except one which was deleted according to the criteria described under "Data Reduction". Temperature ranged from 17.1 - 22.2^{o}C above and 17.8 - 21.5^{o}C below the dam. DOs ranged from 4.33 - 15.97 mg/L above and 5.62 - 12.02 mg/L below the dam. Table A4 shows a summary of the weir aeration coefficients.

PARIS: The Paris dam is a broad-crested concrete structure,3.05 m high, having an S-shaped alignment in plan view (see Figure A3). It has a sloping face and is located on the Grand River in the Town of Paris. Data were collected on August 7-8, 1979, and are presented in Table A5. Six of

the twenty-four data points were rejected since they did not meet the criteria stated previously. Temperature ranged from 20.8 - 22.6°C above and 19.5 - 22°C below the dam. DOs ranged from 6.26 - 15.62 mg/L above and 7.86 - 12.61 mg/L below the dam. See Table A6 for a summary of the weir aeration coefficients.

GALT: The Galt dam is a broad-crested concrete structure, 3.05 m high with a sloping face. The dam is divided into 3 segments - a main dam and two end dams (see Figures A4 and A5). The western portion of the dam drains the reservoir. The main dam has two openings in the central portion near the foot of the dam. The eastern dam is set 30 m upstream of the main dam. A large weed patch is evident in Figure A4 in the central portion of the dam. Immediately below the weed patch, where the water was jetting out of the two openings, the DO concentration was 11 mg/L - somewhat higher than the water flowing over the dam. The hypolimnetic water behind the dam was colder than the surface water and it is possible that this is responsible for the richer DO. Data collected during the Sept. 25-26, 1979 study are presented in Table A7. Eleven of the thirty data points were rejected based on the criteria stated earlier. Temperature ranged from 15.0-16.7°C above and 15.0-17.1°C below the dam. DOs ranged from 9.0-16.5 mg/L above and 9.5-12.2 mg/L below the dam. A summary of the weir aeration coefficients is given in Table A8.

RESULTS:

Using the computational results tabulated in the Appendix, plots of the DO deficit decrease versus upstream DO deficit were prepared for each dam (Figures A6 to A9). From each of these plots, the weir aeration coefficient, W, was determined for the positive and negative deficit cases from the slopes of the appropriate straight lines shown in the Figures. A summary of the values of W for each dam is presented in Table 1. Using the hourly values of W, tabulated in the Appendix, an average weir aeration coefficient ($\overline{W}$) was computed for each dam; these values are also shown in Table 1. Figure A10 shows a plot of dam coefficient versus dam height. From the plot, the correlation seems to be better for the case of the positive DO deficit coefficients (under-saturation) compared with that of the negative DO deficit coefficients (supersaturation).

TABLE 1 SUMMARY OF DAM AERATION COMPUTATIONS

DAM	OBSERVATIONS		AVG. TEMP.(^oC)		AVG. DO (mg/L)		DAM AERATION COEFFICIENTS				SUMMARY OF W VALUES	
	TOTAL	ACCEPTED	ABOVE	BELOW	ABOVE	BELOW	ABOVE SAT.		BELOW SAT.		MAX.	MIN.
							$\bar{W}$	W	$\bar{W}$	W		
HESPELER	26	23	12.2	13.4	9.82	10.45	0.40	0.57	0.76	0.71	0.911	0.045
PRESTON	27	26	18.9	19.3	9.92	8.86	0.63	0.48	0.21	0.36	0.781	0.037
PARIS	24	18	21.5	21.3	9.98	9.90	0.42	0.49	0.75	0.57	1.00	0.339
GALT	30	19	16.1	15.8	11.91	10.71	0.69	0.68	0.80	0.68	1.00	0.56

Note: W = Dam coefficient determined from plot of deficit decrease vs. deficit above dam.

$\bar{W}$ = Mean of hourly W-values

DISCUSSION OF RESULTS:

Three data sets in Figure A10 (those for Hespeler, Preston and Paris), seem to indicate that there are two coefficients for each dam - one for supersaturation and another for undersaturation. This would imply that for the same absolute magnitude of deficit, the rate of aeration is different from the rate of deaeration. The Galt dam data set shows that the rate is the same for both the undersaturated and supersaturated conditions. However, this observation is based on limited data, since positive deficits were all in the order of 1 mg/L, whereas negative deficits ranged from 2 to 7 mg/L. Various hypotheses to explain the difference will be investigated.

CONCLUSION:

The theory of dam aeration as stated in Butts and Evans (1978); implies that the supersaturated water should deaerate at the same rate as the undersaturated water at the equivalent deficit. However, three of the above data sets do not confirm this theory, although one does. Since no other data are available for these dams, it is suggested that the values obtained from this study be accepted as being valid for use in the calibration of the dynamic water quality model. For the dams with two coefficients, both values are to be used, one for undersaturation and the other for supersaturation. A single value will be used for the dam with one coefficient.

There appears to be a relationship between dam height and the weir aeration coefficient as can be seen in Figure A10 for the case of positive DO deficits. Further investigations will have to be carried out to determine if a definite relationship does exist.

RECOMMENDATION: Further weir aeration studies should be carried out under different flow and hydraulic conditions at each of the three dams, viz., Hespeler, Preston and Paris, to verify that there are two coefficients for each dam and to;

(a) further examine the relationship between dam coefficient and dam height, and

(b) determine the theoretical basis for the two coefficients.

APPENDIX

FIGURES AND TABULATIONS, AND DATA SELECTION CRITERIA
WEIR AERATION - GRAND RIVER BASIN

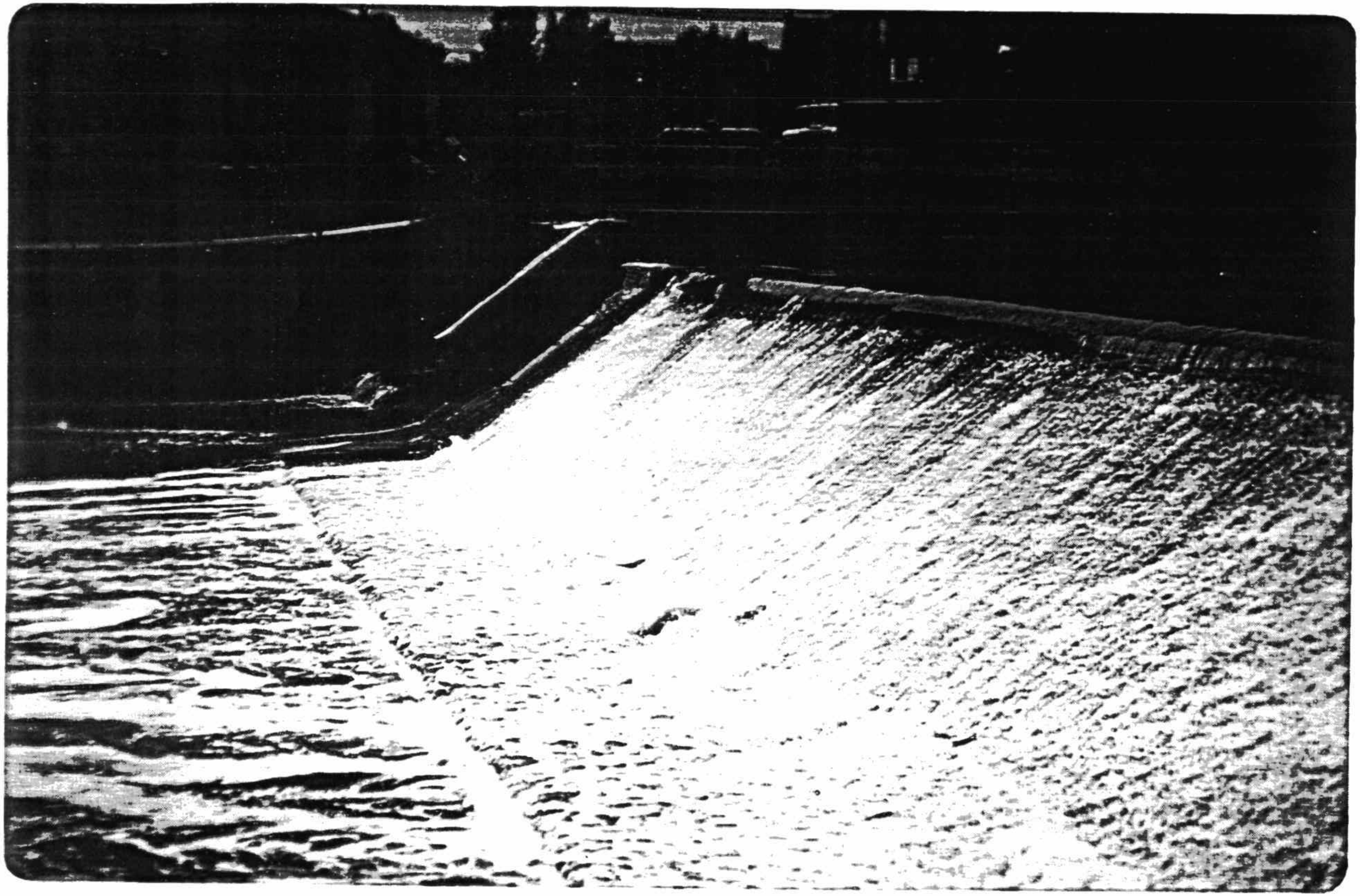

FIGURE A1 HESPELER DAM ON THE SPEED RIVER

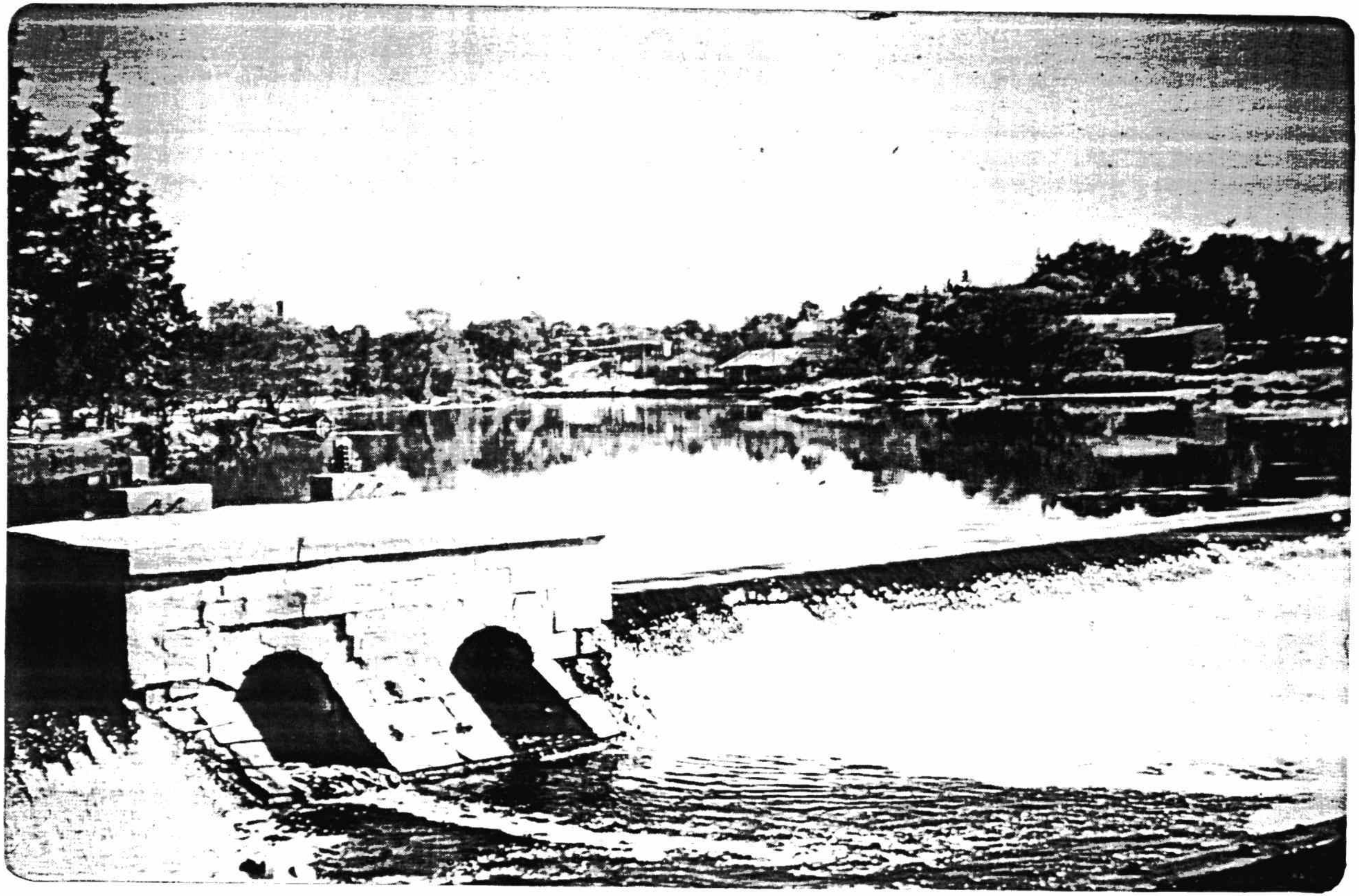

FIGURE A2   PRESTON DAM ON THE SPEED RIVER

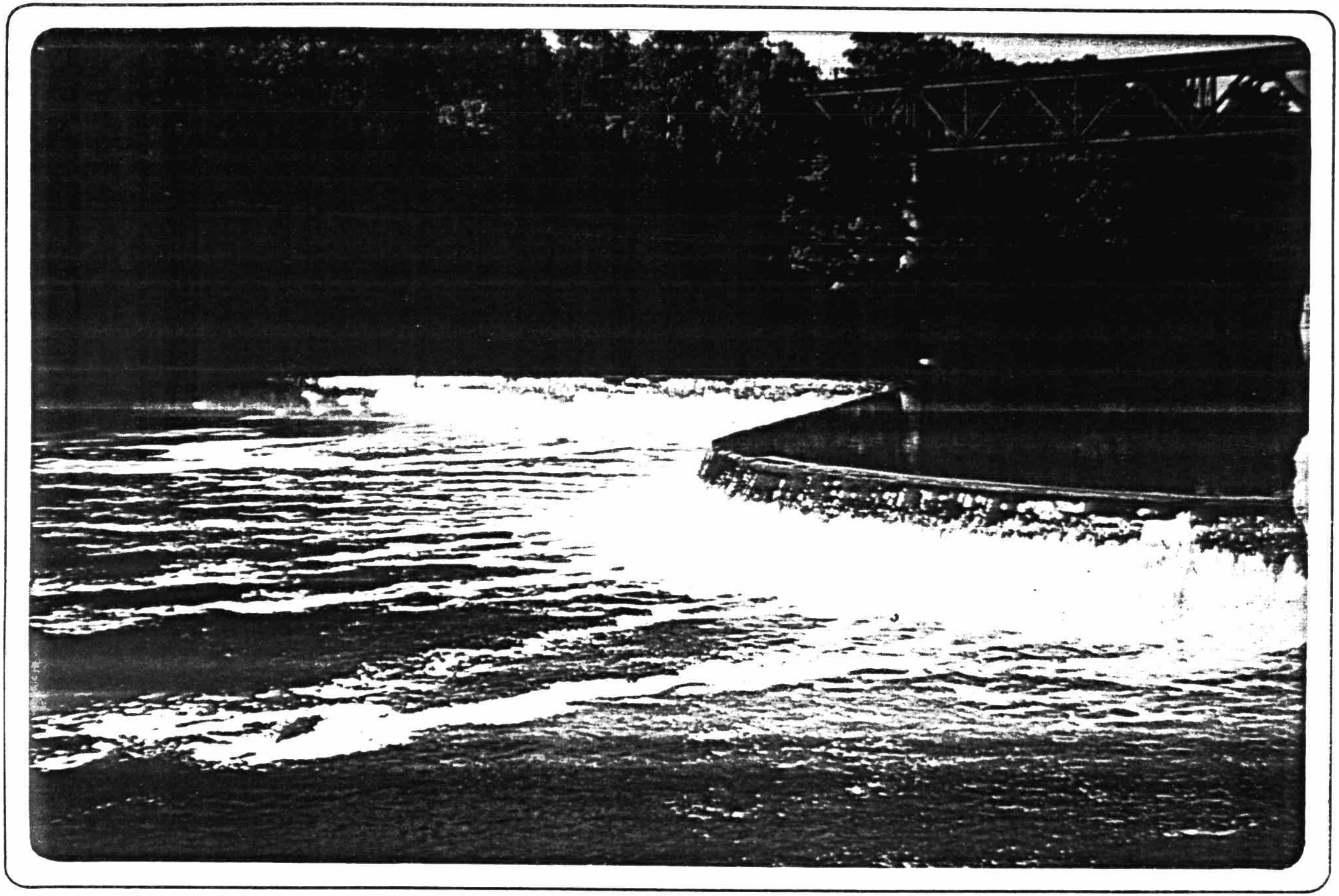

FIGURE A3 PARIS DAM ON THE GRAND RIVER

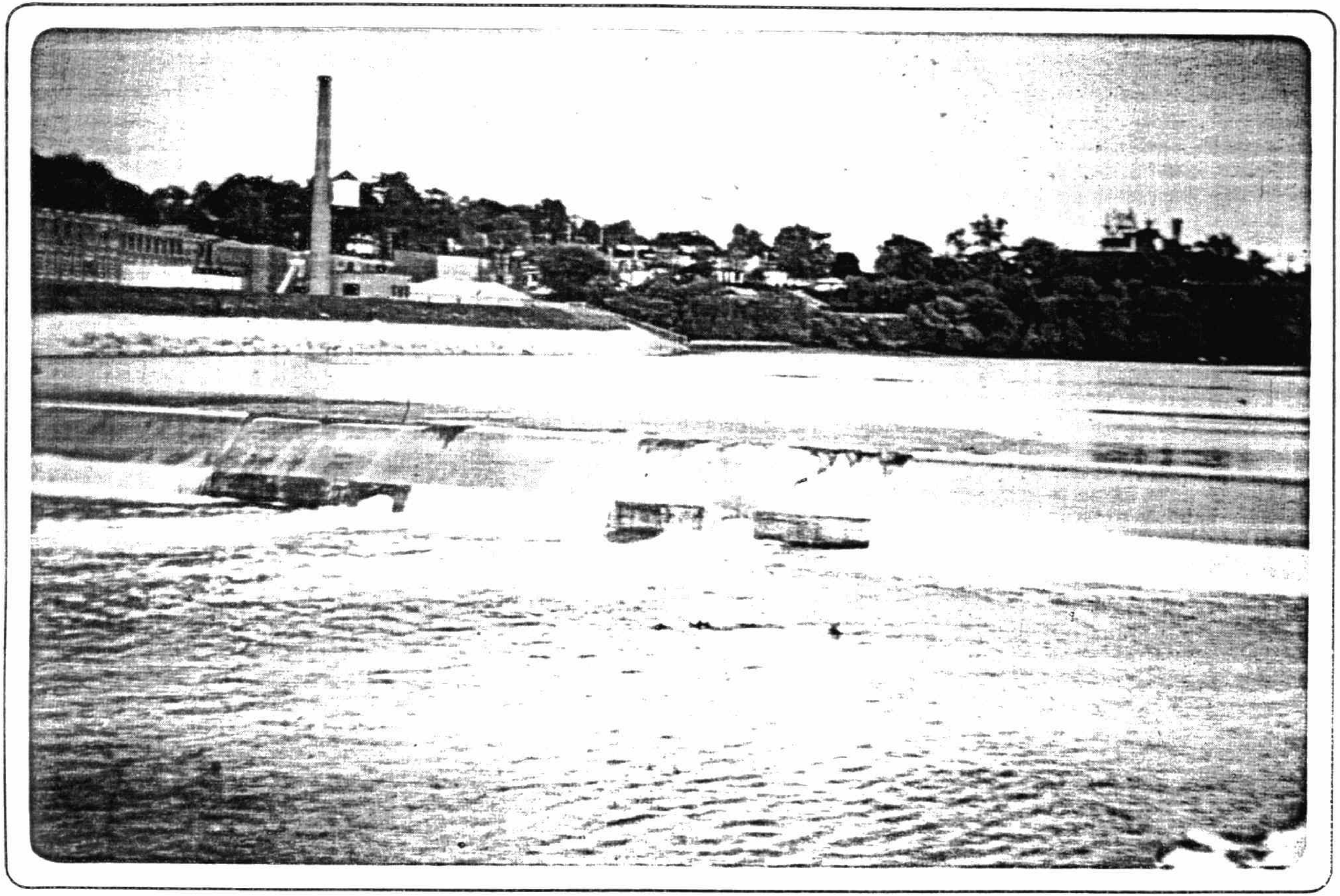

FIGURE A4 GALT DAM ON THE GRAND RIVER

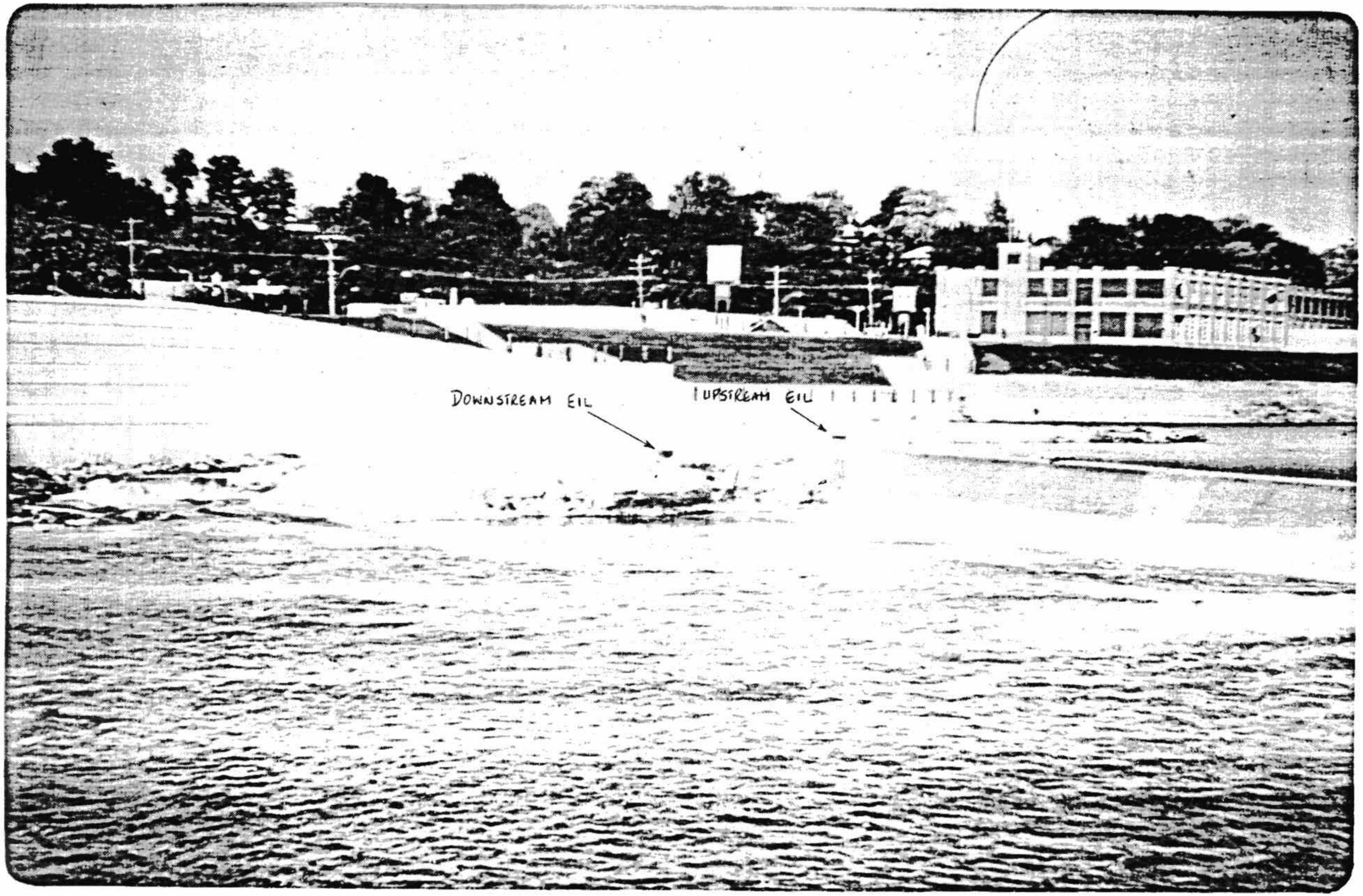

FIGURE A5 GALT DAM ON THE GRAND RIVER

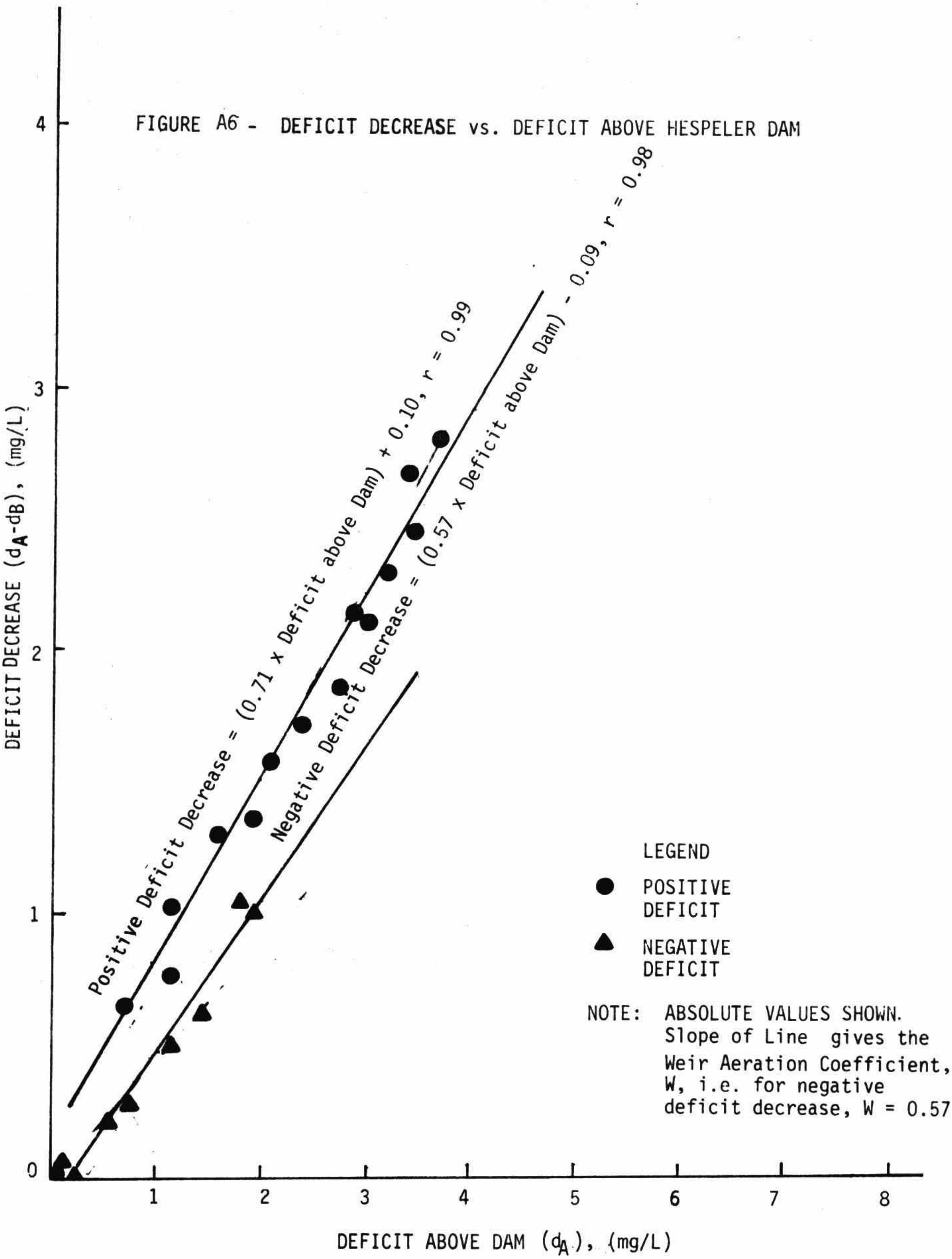

FIGURE A6 - DEFICIT DECREASE vs. DEFICIT ABOVE HESPELER DAM

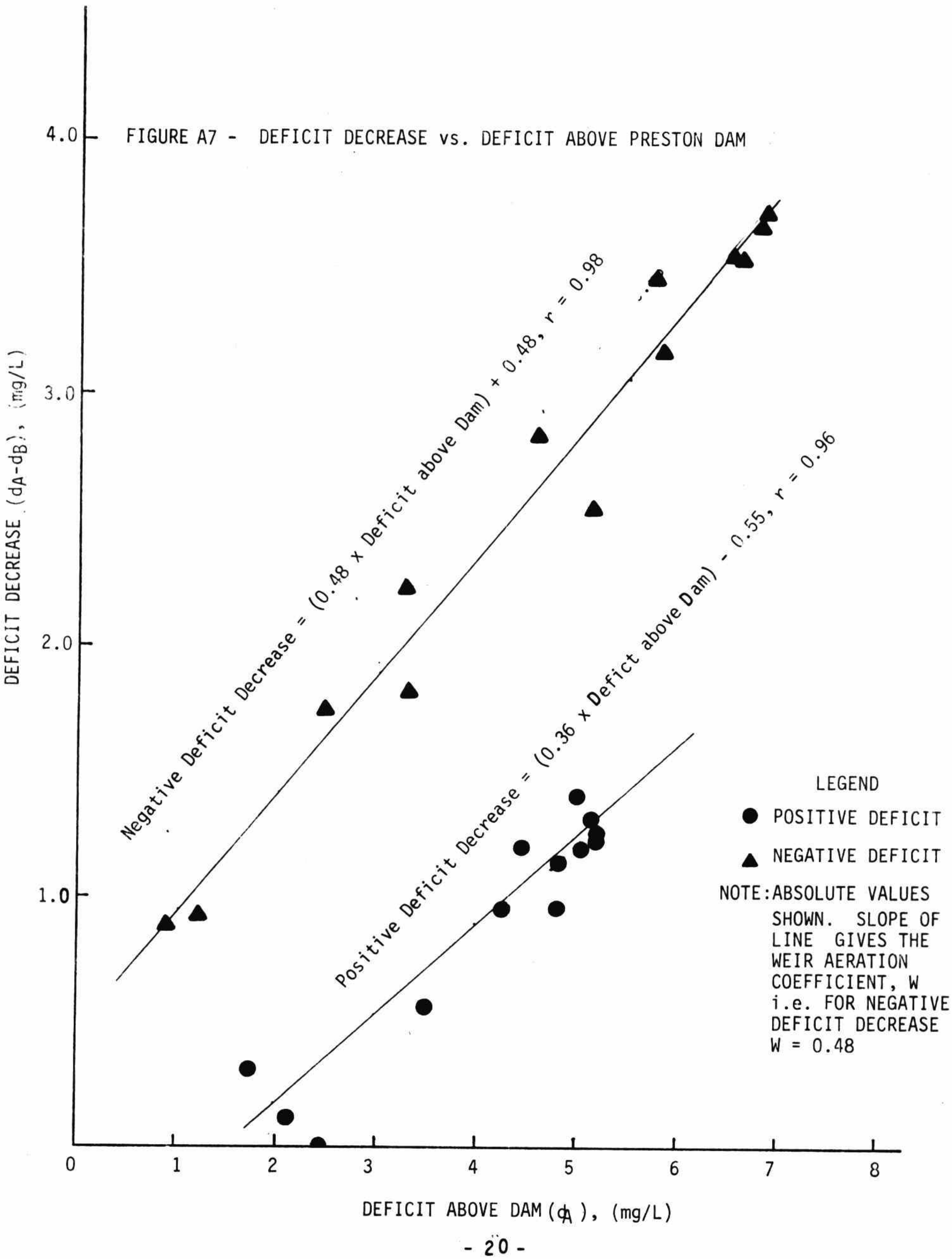
FIGURE A7 - DEFICIT DECREASE vs. DEFICIT ABOVE PRESTON DAM
Negative Deficit Decrease = (0.48 x Deficit above Dam) + 0.48, r = 0.98
Positive Deficit Decrease = (0.36 x Defict above Dam) - 0.55, r = 0.96
LEGEND
POSITIVE DEFICIT
NEGATIVE DEFICIT
NOTE: ABSOLUTE VALUES SHOWN. SLOPE OF LINE GIVES THE WEIR AERATION COEFFICIENT, W i.e. FOR NEGATIVE DEFICIT DECREASE W = 0.48
DEFICIT DECREASE (d_A-d_B), (mg/L)
DEFICIT ABOVE DAM (d_A), (mg/L)
4.0
3.0
2.0
1.0
0
1
2
3
4
5
6
7
8

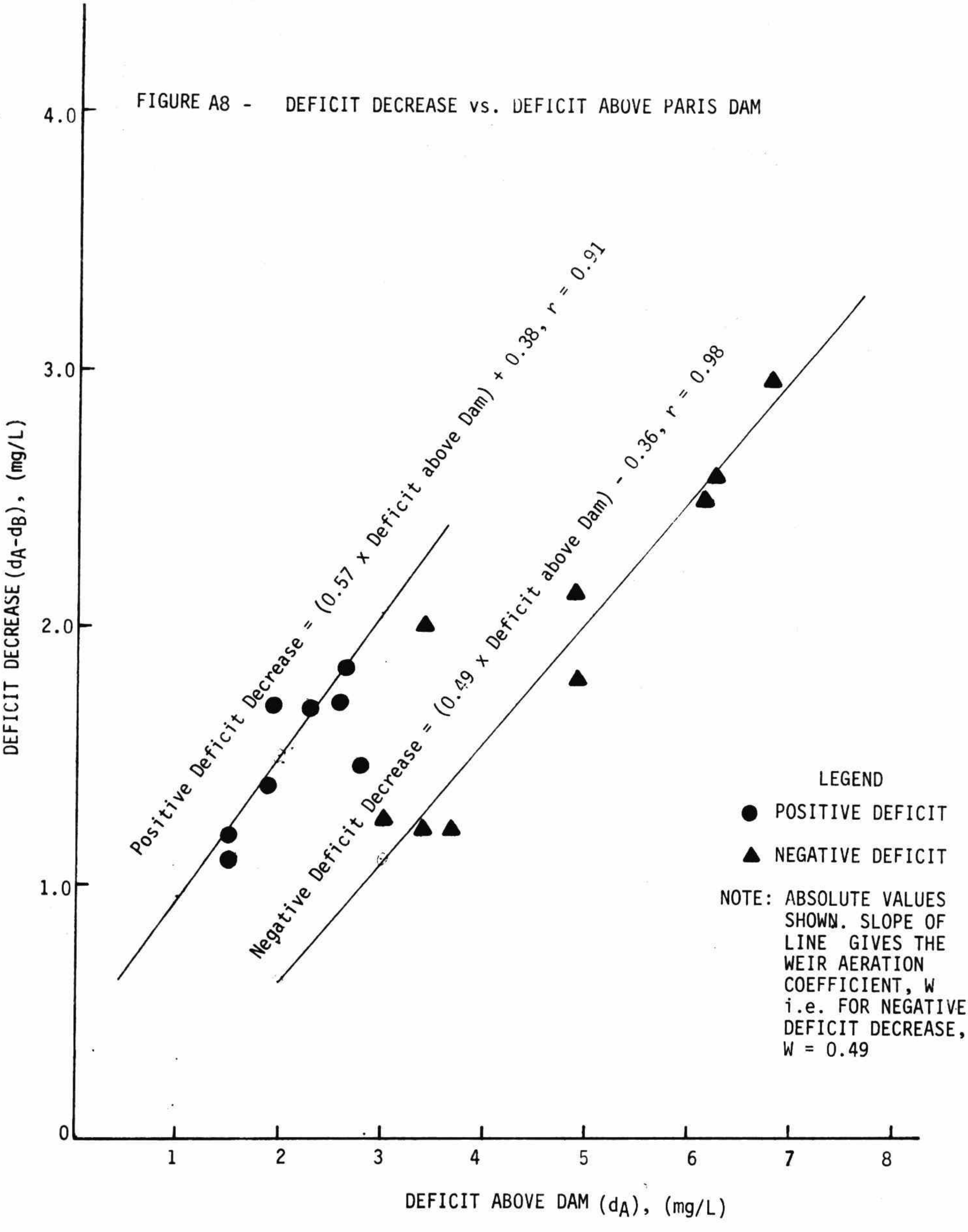

FIGURE A8 - DEFICIT DECREASE vs. DEFICIT ABOVE PARIS DAM

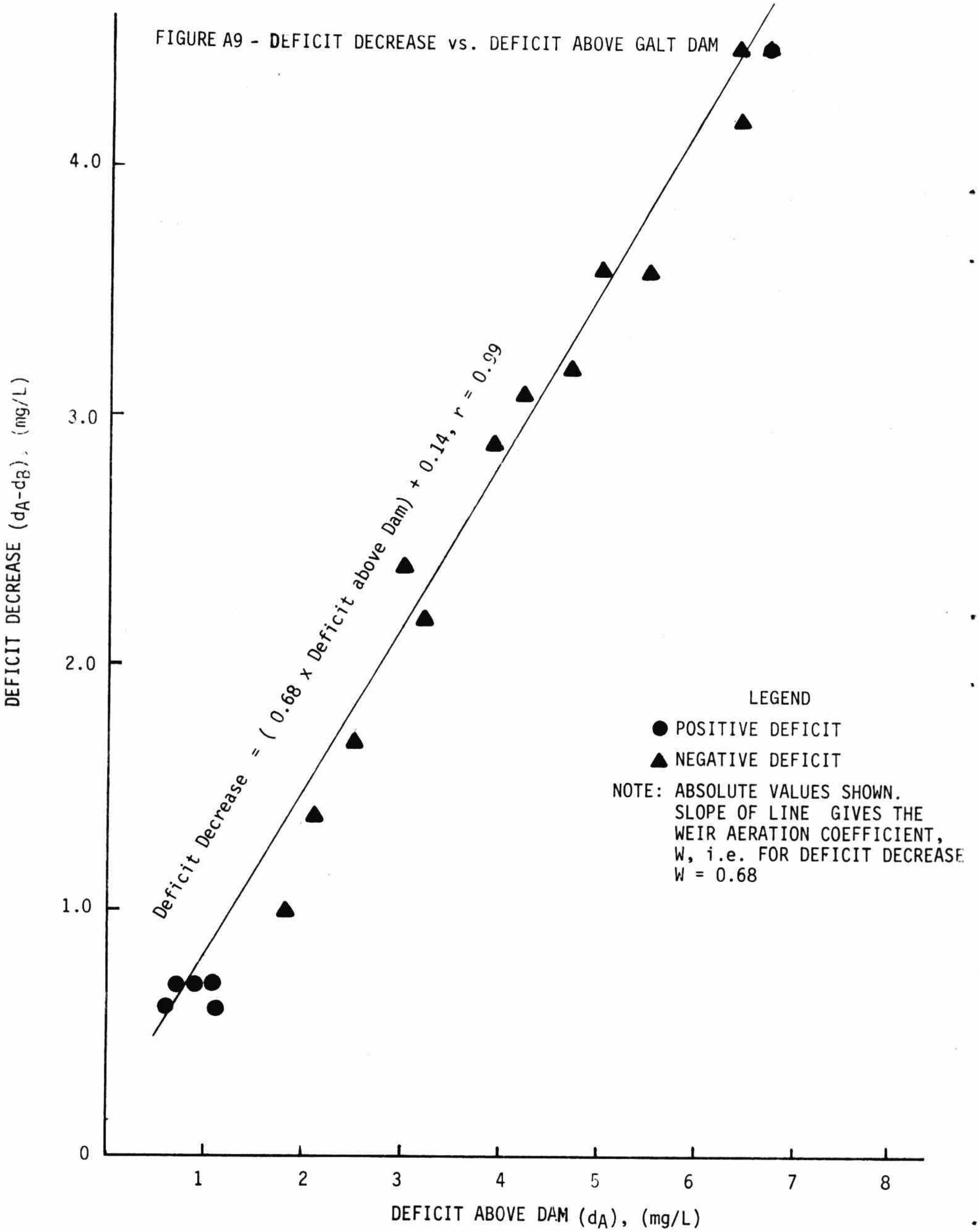
FIGURE A9 - DEFICIT DECREASE vs. DEFICIT ABOVE GALT DAM
Deficit Decrease = (0.68 x Deficit above Dam) + 0.14, r = 0.99
DEFICIT DECREASE (d_A-d_B), (mg/L)
4.0
3.0
2.0
1.0
0
1
2
3
4
5
6
7
8
DEFICIT ABOVE DAM (d_A), (mg/L)
LEGEND
POSITIVE DEFICIT
NEGATIVE DEFICIT
NOTE: ABSOLUTE VALUES SHOWN.
SLOPE OF LINE GIVES THE
WEIR AERATION COEFFICIENT,
W, i.e. FOR DEFICIT DECREASE
W = 0.68

FIGURE A10 - DAM COEFFICIENT "W" VS DAM HEIGHT

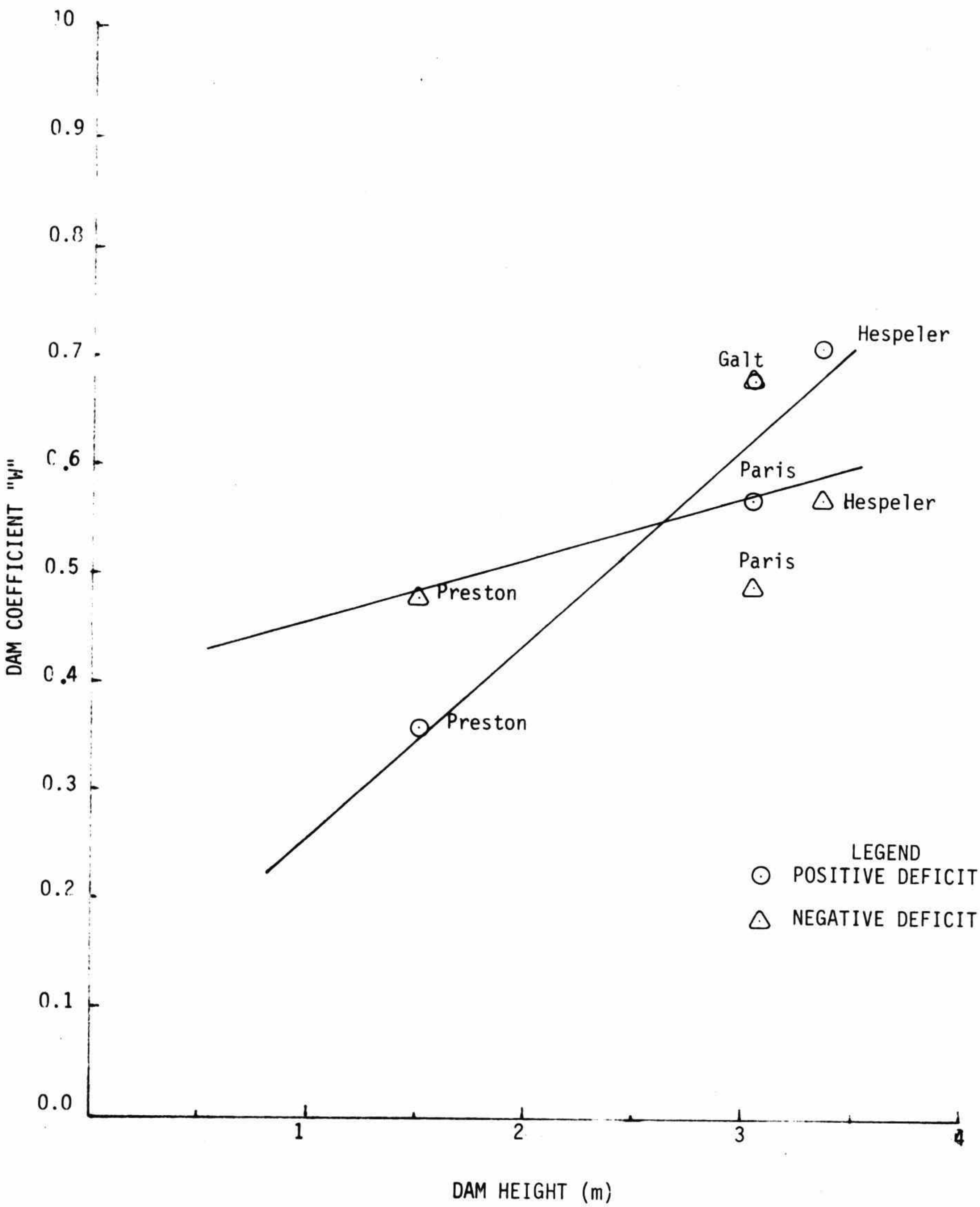

TABLE A1: HESPELER DAM - FIELD SURVEY DATA

DATE	TIME	UPSTREAM		DOWNSTREAM	
		DO (mg/L)	TEMP (oC)	DO (mg/L)	TEMP (oC)
May 29, 1979	15:40	12.38	12.7	11.96	13.5
	16:00	12.40	12.6	11.85	13.5
	17:00	12.47	12.7	11.54	13.5
	18:00	12.62	12.7	11.43	13.5
	19:00	12.11	12.6	11.28	13.5
	20:00	11.86	12.5	11.12	13.5
	21:00	11.48	12.5	10.96	13.5
	22:00	10.94	12.5	10.70	13.5
	23:00	10.83	12.5	10.54	13.5
	24:00	10.02	12.5	10.41	13.6
May 30, 1979	1:00	9.60	12.5	10.39	13.5
	2:00	9.18	12.4	10.23	13.5
	3:00	8.72	12.2	10.04	13.4
	4:00	8.47	12.0	9.92	13.2
	5:00	8.13	12.0	9.71	13.2
	6:00	7.93	11.8	9.71	13.2
	7:00	7.75	11.7	9.73	13.1
	8:00	7.51	11.6	9.64	13.1
	9:00	7.51	11.6	9.65	13.0
	10:00	7.29	11.5	9.75	13.0
	11:00	7.53	11.7	9.86	13.2
	12:00	8.07	11.7	9.86	13.2
	13:00	8.93	12.0	9.99	13.4
	14:00	9.67	12.1	10.12	13.5
	15:00	10.73	12.2	10.41	13.6
	15:40	11.18	12.8	10.85	13.3
MEAN:		9.82	12.2	10.45	13.4

TABLE A2: CALCULATION OF WEIR AERATION COEFFICIENT FOR HESPELER DAM

TIME	d_A	d_B	d_A-d_B	W	REMARKS
15:30	-1.71	-1.47	-0.24	-	Discarded
16:00	-1.71	-1.36	-0.35	-	Discarded
17:00	-1.80	-1.05	-1.05	0.42	
18:00	-1.95	-0.94	-1.01	0.52	
19:00	-1.42	-0.79	-0.63	0.44	
20:00	-1.14	-0.63	-0.51	0.45	
21:00	-0.75	-0.47	-0.28	0.37	
22:00	-0.22	-0.21	-0.01	0.45	
23:00	-0.11	-0.05	-0.06	0.50	
24:00	0.70	0.05	0.65	0.93	
01:00	1.13	0.10	1.03	0.91	
02:00	1.57	0.26	1.31	0.84	
03:00	2.06	0.47	1.59	0.77	
04:00	2.36	0.63	1.73	0.73	
05:00	2.71	0.84	1.87	0.69	
06:00	2.96	0.84	2.12	0.72	
07:00	3.16	0.85	2.31	0.73	
08:00	3.42	0.95	2.47	0.72	
09:00	3.42	0.95	2.47	0.72	
10:00	3.67	0.85	2.82	0.77	
11:00	3.38	0.69	2.69	0.80	
12:00	2.84	0.69	2.15	0.76	
13:00	1.90	0.53	1.37	0.72	
14:00	1.14	0.37	0.77	0.68	
15:00	0.05	0.05	0.00	-	a (see criteria table below)
15:45	-0.53	-0.32	-0.21	0.40	

CRITERIA FOR OMITTING DATA

a - C_A & $C_B < C_S$; $C_B \geq C_A$
b - $C_A < C_S$; $C_B \leq C_S$
c - C_A & $C_B > C_S$; $C_B \leq C_A$
d - $C_A > C_S$; $C_B \geq C_S$

MEAN COEFFICIENT FOR POSITIVE DEFICITS = 0.76
MEAN COEFFICIENT FOR NEGATIVE DEFICITS = 0.40

TABLE A3: PRESTON DAM - FIELD SURVEY DATA

DATE	TIME	UPSTREAM DO (mg/L)	UPSTREAM TEMP (oC)	DOWNSTREAM DO (mg/L)	DOWNSTREAM TEMP (oC)
July 3, 1979	12:00	10.91	17.1	9.85	17.8
	13:00	12.90	17.4	10.44	18.5
	14:00	14.11	17.9	10.96	19.5
	15:00	15.16	18.4	11.29	20.6
	16:00	15.90	19.0	12.02	20.8
	17:00	15.97	19.7	12.01	21.2
	18:00	15.95	20.0	11.94	21.5
	19:00	15.60	20.3	11.81	21.5
	20:00	14.86	20.4	11.53	21.2
	21:00	13.60	20.2	10.83	20.6
	22:00	11.64	19.9	9.86	20.0
	23:00	9.36	19.4	8.68	19.4
	24:00	7.21	19.0	7.34	19.0
July 4, 1979	1:00	5.91	18.7	6.51	18.6
	2:00	5.20	18.5	6.13	18.6
	3:00	4.65	18.4	5.82	18.4
	4:00	4.44	18.4	5.71	18.2
	5:00	4.33	18.2	5.62	18.1
	6:00	4.33	18.1	5.63	18.0
	7:00	4.45	17.9	5.78	18.0
	8:00	4.63	17.7	6.04	17.8
	9:00	5.19	17.6	6.38	17.8
	10:00	7.15	17.8	7.23	17.9
	11:00	7.82	18.0	8.28	18.3
	12:00	10.22	19.1	9.33	19.1
	13:00	12.42	20.2	10.60	20.2
	14:00	13.90	22.2	11.51	21.0
MEAN		9.92	18.9	8.86	19.3

TABLE A4: CALCULATION OF WEIR AERATION COEFFICIENT FOR PRESTON DAM

TIME	d_A	d_B	d_A-d_B	W	REMARKS
12:00	-1.19	-0.26	-0.93	0.78	
13:00	-3.24	-0.99	-2.25	0.69	
14:00	-4.55	-1.69	-2.86	0.63	
15:00	-5.70	-2.22	-3.48	0.61	
16:00	-6.55	-2.98	-3.57	0.55	
17:00	-6.75	-3.05	-3.70	0.55	
18:00	-6.78	-3.03	-3.75	0.55	
19:00	-6.48	-2.90	-3.58	0.55	
20:00	-5.76	-2.56	-3.20	0.56	
21:00	-4.47	-1.77	-2.70	0.60	
22:00	-2.45	-0.69	-1.76	0.72	
23:00	-0.08	0.60	-0.68	-	d (see criteria table below)
24:00	2.14	2.01	0.13	0.06	
01:00	3.50	2.92	0.58	0.17	
02:00	4.25	3.30	0.95	0.22	
03:00	4.81	3.65	1.16	0.24	
04:00	5.02	3.80	1.22	0.24	
05:00	5.17	3.91	1.26	0.24	
06:00	5.19	3.91	1.28	0.25	
07:00	5.11	3.77	1.34	0.26	
08:00	4.97	3.54	1.43	0.29	
09:00	4.43	3.21	1.22	0.26	
10:00	2.43	2.34	0.09	0.04	
11:00	1.72	1.40	0.32	0.19	
12:00	-0.89	0.00	-0.89	1.0	
13:00	-3.29	-1.46	-1.83	0.56	
14:00	-5.10	-2.52	-2.58	0.51	

CRITERIA FOR OMITTING DATA

a - C_A & $C_B < C_S$; $C_B \geq C_A$
b - $C_A < C_S$; $C_B \leq C_S$
c - C_A & $C_B > C_S$; $C_B \leq C_A$
d - $C_A > C_S$; $C_B \geq C_S$

MEAN COEFFICIENT FOR POSITIVE DEFICITS = 0.21
MEAN COEFFICIENT FOR NEGATIVE DEFICITS = 0.63

TABLE A5: PARIS DAM - FIELD SURVEY DATA

DATE	TIME	UPSTREAM		DOWNSTREAM	
		DO (mg/L)	TEMP (°C)	DO (mg/L)	TEMP (°C)
Aug 8, 1979	11:00	7.53	21.0	8.55	21.5
	12:00	8.41	21.0	8.96	21.2
	13:00	9.21	20.9	9.50	21.2
	14:00	10.27	20.9	9.97	21.1
	15:00	11.99	20.8	10.66	21.2
	16:00	12.59	21.2	11.35	21.3
	17:00	13.79	21.3	11.94	21.5
	18:00	15.11	21.3	12.43	21.7
	19:00	15.62	21.6	12.61	21.7
	20:00	14.93	21.8	12.39	21.9
	21:00	13.67	21.8	11.48	22.0
	22:00	12.16	22.1	10.95	22.0
	23:00	12.14	22.2	10.15	22.0
	24:00	9.72	22.2	9.82	21.9
Aug 9, 1979	01:00	8.92	22.1	9.39	21.8
	02:00	8.30	22.6	9.15	21.7
	03:00	7.85	21.9	8.93	21.4
	04:00	7.40	21.8	8.67	21.3
	05:00	7.04	21.7	8.54	21.0
	06:00	6.70	21.4	8.45	21.0
	07:00	6.44	21.1	8.28	20.4
	08:00	6.26	20.9	7.87	20.1
	09:00	6.42	20.9	8.47	19.8
	10:00	7.10	21.0	9.07	19.5
MEAN		9.98	21.5	9.90	21.3

TABLE A6: CALCULATION OF WEIR AERATION COEFFICIENT FOR PARIS DAM

TIME	d_A	d_B	d_A-d_B	W	REMARKS
11:00	1.46	0.36	1.10	0.75	
12:00	0.58	0.00	0.58	-	
13:00	0.20	-0.54	0.34	-	c (see criteria
14:00	-1.26	-0.99	-0.27	0.21	c table below)
15:00	-2.96	-1.70	-1.26	0.43	
16:00	-3.63	-2.40	-1.23	0.34	
17:00	-4.85	-3.03	-1.82	0.38	
18:00	-6.17	-3.55	-2.62	0.43	
19:00	-6.73	-3.73	-3.00	0.45	
20:00	-6.07	-3.54	-2.53	0.42	
21:00	-4.81	-2.65	-2.16	0.45	
22:00	-3.35	-2.12	-1.23	0.37	
23:00	-3.34	-1.32	-2.02	0.61	Discard
24:00	-0.92	-0.97	0.05	-	c
01:00	-0.11	-0.53	0.42	-	c
02:00	-0.53	-0.27	0.80	-	b
03:00	1.00	0.00	1.00	-	b
04:00	1.46	0.27	1.19	0.82	
05:00	1.84	0.45	1.39	0.76	
06:00	2.23	0.54	1.69	0.76	
07:00	2.54	0.82	1.72	0.68	
08:00	2.75	1.28	1.47	0.54	
09:00	2.59	0.74	1.85	0.71	
10:00	1.89	0.19	1.70	0.91	

CRITERIA FOR OMITTING DATA

a - C_A & $C_B < C_S$; $C_B \geq C_A$
b - $C_A < C_S$; $C_B \leq C_S$
c - C_A & $C_B > C_S$; $C_B \leq C_A$
d - $C_A > C_S$; $C_B \geq C_S$

MEAN COEFFICIENT FOR POSITIVE DEFICITS = 0.75
MEAN COEFFICIENT FOR NEGATIVE DEFICITS = 0.42

TABLE A7: GALT DAM - FIELD SURVEY DATA

DATE	TIME	UPSTREAM		DOWNSTREAM	
		DO (mg/L)	TEMP (°C)	DO (mg/L)	TEMP (°C)
Sep 25,1979	13:00	10.0	15.0	10.3	15.0
	14:00	9.5	15.5	10.1	15.1
	15:00	9.6	15.8	10.1	15.6
	16:00	9.2	15.5	9.8	15.7
	17:00	9.0	15.5	9.7	15.1
	18:00	9.0	15.5	9.6	15.1
	19:00	9.6	15.6	9.5	15.2
	20:00	10.3	15.6	9.6	15.1
	20:00	12.9	16.0	10.7	15.1
	22:00	14.9	16.2	11.5	15.3
	23:00	16.2	16.5	11.9	15.6
	24:00	16.5	16.6	12.2	15.9
Sep 26,1979	01:00	16.5	16.7	12.2	15.9
	02:00	16.2	16.7	12.1	16.0
	03:00	15.3	16.6	11.8	16.1
	04:00	14.5	16.5	11.4	16.1
	05:00	14.0	16.5	11.1	15.9
	06:00	13.8	16.4	11.0	15.9
	07:00	13.1	16.3	11.0	15.7
	08:00	12.4	16.2	10.8	15.8
	09:00	12.0	16.1	10.7	15.6
	10:00	11.7	16.0	10.8	15.6
	11:00	11.4	16.0	11.2	15.6
	12:00	11.1	15.9	11.0	16.0
	13:00	11.5	16.1	10.7	16.2
	14:00	9.8	16.1	10.6	16.3
	15:00	9.7	16.4	10.2	16.5
	16:00	9.4	16.4	10.2	16.5
	17:00	9.1	16.2	9.84	17.2
	17:30	9.2	16.1	9.80	16.7
MEAN		11.9	16.1	10.7	15.8

TABLE A8: CALCULATION OF WEIR AERATION COEFFICIENT FOR GALT DAM

TIME	d_A	d_B	d_A-d_B	W	REMARKS
13:00	0.0	-0.2	0.2	UDF	
14:00	0.6	0.0	0.6	-	b (see criteria
15:00	0.4	-0.1	0.5	-	b table below)
16:00	0.9	0.2	0.7	0.78	
17:00	1.1	0.4	0.7	0.64	
18:00	1.1	0.5	0.6	0.55	
19:00	0.4	0.6	-0.2	-	a
20:00	-0.3	0.5	-0.8	-	d
21:00	-3.0	-0.6	-2.4	0.80	
22:00	-5.0	-1.4	-3.6	0.72	
23:00	-6.4	-1.9	-4.5	0.70	
24:00	-6.7	-2.2	-4.5	0.67	
01:00	-6.7	-2.2	-4.5	0.67	
02:00	-6.4	-2.2	-4.2	0.66	
03:00	-5.5	-1.9	-3.6	0.65	
04:00	-4.7	-1.5	-3.2	0.68	
05:00	-4.2	-1.1	-3.1	0.74	
06:00	-3.9	-1.0	-2.9	0.74	
07:00	-3.2	-1.0	-2.2	0.69	
08:00	-2.5	-0.8	-1.7	0.68	
09:00	-2.1	-0.7	-1.4	0.67	
10:00	-1.8	-0.8	-1.0	0.56	
11:00	-1.5	-1.2	-0.3	0.20	Discard
12:00	-1.1	-1.1	0.0	0.0	Discard
13:00	-0.6	-0.8	0.2	-	c
14:00	0.1	-0.7	0.8	-	b
15:00	0.2	-0.4	0.6	-	b
16:00	0.5	-0.4	0.9	-	b
17:00	0.8	0.1	0.9	-	b
17:30	0.7	0.0	0.7	-	

CRITERIA FOR OMITTING DATA

a - C_A & $C_B < C_S$; $C_B \geq C_A$
b - $C_A < C_S$; $C_B \leq C_S$
c - C_A & $C_B > C_S$; $C_B \leq C_A$
d - $C_A > C_S$; $C_B \geq C_S$

MEAN COEFFICIENT FOR POSITIVE DEFICITS = 0.8
MEAN COEFFICIENT FOR NEGATIVE DEFICITS = 0.69

DETAILED EXPLANATION FOR SELECTING VALID DATA POINTS

" (1) C_A and $C_B < C_s$; $C_B < C_A$
(2) $C_A < C_s$; $C_B > C_s$
(3) C_A and $C_B > C_s$; $C_B > C_A$
(4) $C_A > C_s$; $C_B < C_s$

Theoretically, these four conditions cannot occur. However, they do for a number of practical reasons, some of which are: inaccurate DO meters and/or probes, poor placement of the probe (mainly the downstream one), observation errors relative to either DO or temperature readings, stream DO conditions too near saturation, and impurities and excessive particular matter in the water.

Excessively high deficit ratios for this study have been defined as values exceeding 4.0. Values greater than 4.0 may not indicate procedural errors but generally they do. Consequently, since procedural errors cannot be readily separated from unbiased fact, any values not meeting this criterion have been rejected.

Also, unrealistically high W-values can result when observed DOs approach saturation as a limit. To reduce the influence on the overall result of this occurrence, all sets of DO observations having values within the range of $C_s \pm 1.0$ mg/L have been rejected. A simple example will illustrate the significance of this. Saturation values used in this study were derived with the American Society of Engineers' forumula[13]:

$$C_s = 14.652 - 0.41022T + 0.0079910T^2 - 0.000077774T^3 \qquad (3)$$

Assume at midmorning, a stream at 20.1°C had DOs upstream and downstream of a dam of 7.85 and 7.95 mg/L, respectively. From equation 3, C_s equals 9.00 mg/L, which for the given conditions yields a deficit ratio of 1.1. Later in the afternoon the water warms to 21.5°C (C_s = 8.75 mg/L) and upstream and downstream DOs increase to 8.60 mg/L and 8.70 mg/L, respectively, as a result of photosynthetic oxygen production. Under this new set of conditions where C_A and C_B are within the range of $C_s \pm 1.0$ mg/L, the

deficit ratio is 3, which would produce an unrealistic W-value many times greater than that calculated for early morning conditions. Unfortunately, a considerable amount of data was collected when C_A or C_B approached saturation; a good example is that collected for the Busse Woods (South) Dam (No. 29). All observations fell within 1.0 mg/L of C_s causing total rejection of all observation sets. Without rejection, an inflated dam coefficient greater than 3 would have resulted. The dam coefficient computed for 3:30 p.m. conditions (see appendix) for this structure is 5.2, an unusable value. If the upstream and downstream DO differential had been only 0.15 mg/L instead of 0.30 mg/L, a coefficient of only 1.5 would have resulted, cleary a high but usable value."

Excerpted from Page 9, Thomas A. Butts and Ralph L. Evans, 1978. Effects of Channel Dams on Dissolved Oxygen Concentration in Northern Illinois Streams. Illinois State Water Circular 132/78.

PART II SEDIMENT OXYGEN DEMAND

DATA COLLECTION: The sediment oxygen demand (SOD) of dammed sediments was measured in situ using the dome respirometer, designed and built by River Systems, Water Resources Branch (see Figure 3). These tests were carried out in the reservoirs behind the dams at Hespeler, Preston and Paris.

A dark dome as well as a light dome respirometer were used to measure SOD. The light dome SOD rates indicate the effect of photosynthetic oxygen production by biomass, if there is any. The oxygen demand of organic matter is characterized by the dark dome SOD rates. In order to account for any activity by the suspended bacteria and algae, a compensating BOD test was performed in parallel with the respirometer test at each site using a dark bottle. Sites for respirometer emplacement were chosen in areas that were generally representative of the bottom sediments in the reservoirs and under not more than 1 m of water. Duration of measurement depended on how fast the DO was changing and ranged from 1.17 h - 3.5 h.

DESCRIPTION OF STUDY SITES

HESPELER: The investigation was carried out at two locations upstream of the dam at 300 and 315 m, and at both locations dark domes were used. The first respirometer was located in very slow moving water close to the bank. A 12-volt battery was used to power the stirrer. The

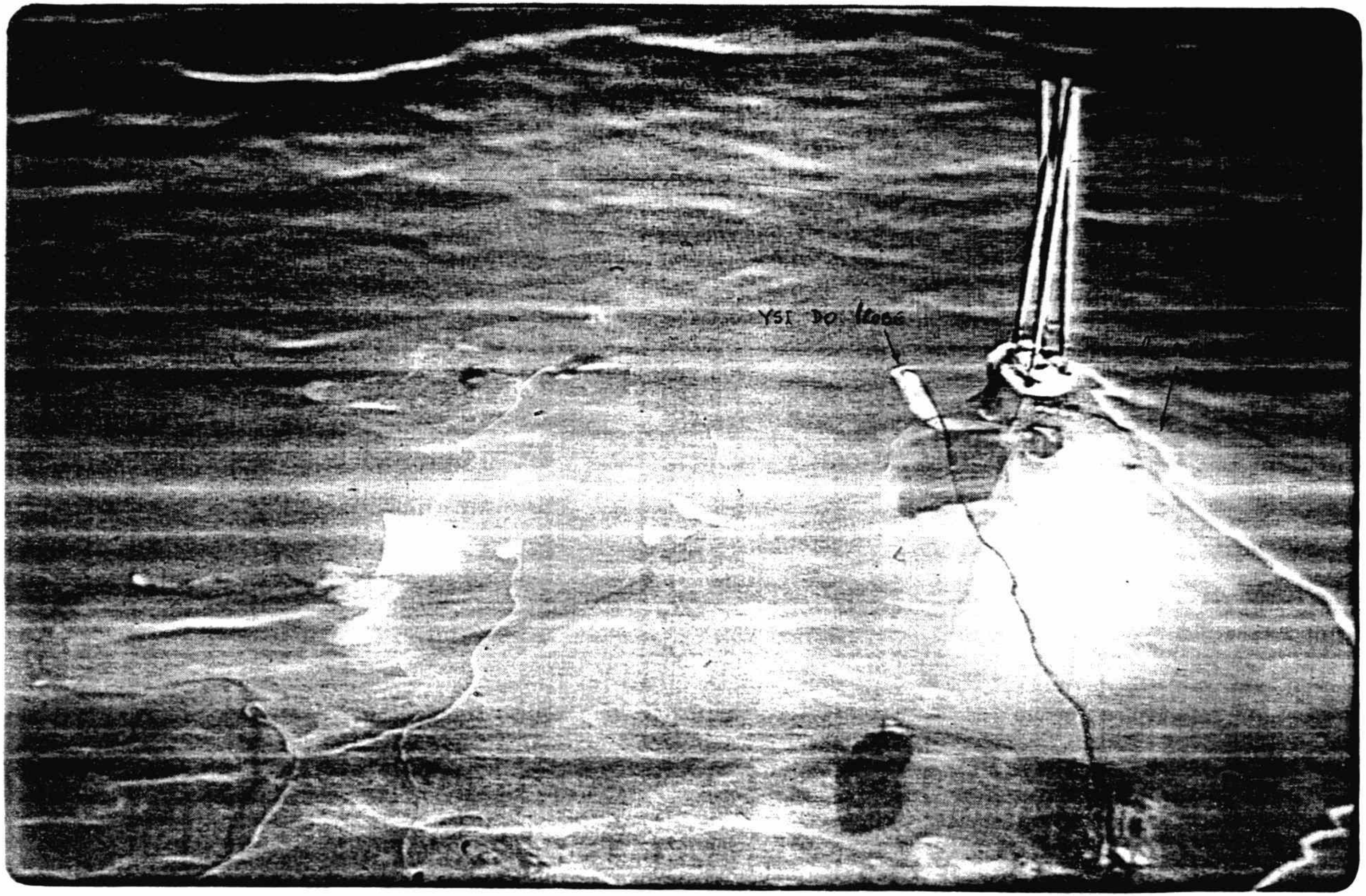

FIGURE3 DARK DOME RESPIROMETER IN SITU

second respirometer was located towards the centre of the stream in faster moving water and a 6-volt battery was used. (Note: A 6-volt battery is sufficient to power the stirrers but since another one was not available that day, a 12-volt battery had to be used on the first respirometer.) The bottom sediment was more silty and organic at the first location than at the second. There was no evidence of activity from suspended bacteria and algae. ($\triangle$BOD = 0).

PRESTON: Two respirometers were placed together at approximately 10m upstream of the dam. One was a dark dome, the other was a light dome. The bottom sediment was silty and organic and both domes were located in slow moving water. 6-volt batteries were used to power the stirrers. As in the previous case, there was negligible activity from suspended bacteria and algae. (ΔBOD = 0). The average DO concentration in the river was around 6.8 mg/L during the measurement.

PARIS: Again, two respirometers were used for this study - a dark dome and a light dome. They were located in slow moving water, at approximately 500 m upstream of the dam. The compensating BOD test showed some activity from the suspended bacteria and algae. (Δ BOD = 0.1 mg/L). The bottom sediment was organic with at least 50 cm of silt. There was also a strong smell of hydrogen sulphide in the vicinity of the domes suggesting anoxic conditions near the sediments. The average DO concentration in the river during the measurement was around 7.6 mg/L.

RESULTS: A Summary of the SOD at each site is presented in Table 2.

TABLE 2 SUMMARY OF SOD AT EACH SITE

STATION:	AVG. TEMP (^{o}C)	SOD $g\ O_2\ \overline{m}^2\ day^{-1}$ LIGHT DOME	SOD $g\ O_2\ \overline{m}^2\ day^{-1}$ DARK DOME
HESPELER	13.25	-	5.39 (1st Location) 1.79 (2nd Location)
PRESTON	18.75	3.15	2.52
PARIS	21.5	3.02	4.88

DISCUSSION: At Hespeler, the higher mixing rate of the circulating pump and the placement of the second respirometer in a faster moving body of water are probably responsible for the large difference in the two SOD values. The higher river velocity usually prevents settling of organic matter and thus the lower SOD rates appear reasonable. However, the lower SOD rate may also be due to the differential stirring rates caused by the use of both 12-volt and 6-volt batteries.

At Preston, the higher calculated SOD level in the light dome indicates that there was probably no significant photosynthetically active biomass present. Both measurements from the light and dark domes can be taken as a measure of the SOD. The difference of 0.63 mg/L of oxygen uptake between the light and dark domes is likely to be attributable to local and experimental discrepancies, and is not considered to be significant.

At Paris, the lower value obtained from the light dome indicates production of oxygen from plankton and other aquatic plants as was suggested by results from the compensating dark-bottle test.

CONCLUSION: This study shows that the uptake of oxygen by organic matter is significant especially at Hespeler and Preston dams.

RECOMMENDATION: More SOD studies should be done to confirm the nature of these findings and their areal extent.

The effect of dome mixing rate on measured SOD should be tested and verified.

The relationship of organic content of bottom to SOD should be established by bench-scale or field experimentation.